Vehicle Dynamics Performance of CLARITY FUEL CELL

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ABSTRACT

The dynamic performance targeted with the CLARITY FUEL CELL has the unique new appeal of a fuel cell vehicle with a full complement of universal values of a passenger car, such as ease of driving. The Accord PHEV, which is a vehicle in the same class as the CLARITY FUEL CELL and has a high level of performance, was chosen as the benchmark for performance objectives. Specifically, this means that the CLARITY FUEL CELL provides a solid driving experience, making full use of one of the distinctive advantages of electric vehicles, that they allow drivers to freely control the car's speed using only the accelerator pedal. It provides handling performance that demonstrates how easily course-holding can be managed when driving, a smooth, comfortable ride from the moment the car starts moving, and a positive brake feel that makes the car easy to control in all the various driving scenarios encountered from day to day. It is also extremely quiet. The developed vehicle satisfied the objectives and successfully realized the image that was desired.

1. Introduction

Automobiles are on a course of evolution toward electrification and a shift toward next-generation alternative fuels as ways to address issues such as the growing demand for fuel-saving technology to deal with the depletion of fossil fuel resources, as well as the issue of global warming caused by CO_2 and other such environmental issues. Fuel cell vehicles (FCV) involve the use of high-pressure hydrogen tanks and complex auxiliary devices, as well as modifications to vehicle body construction and other such measures to protect these systems from the shock of collisions. The resulting increase in weight has become an issue. While lower rolling resistance coefficients (RRC) for tires have been promoted in order to increase fuel efficiency, the adoption of tires with lower RRC also introduces the important issue of assuring grip performance, which is reduced by a lower RRC, and providing satisfactory dynamic performance with a heavy vehicle body.

The CLARITY FUEL CELL has a major role to play in FCV dissemination and expansion. In order to provide the joy of free mobility to every occupant, including passengers, this vehicle was developed using the most up-to-date technologies.

The vehicle had a distinctive layout[(1)] with the hydrogen tank mounted behind the rear seat and tire covers added to the rear wheel houses to reduce air resistance. Particular attention was therefore focused on dealing with the handling performance issues that arose as a result of this layout. The longitudinal distribution of weight was shifted more toward the rear than the common front wheel drive (FF) vehicle with an internal combustion engine (ICE). In addition, the placement of tire covers on the outside of the wheel houses added to the constraints on the size of tire. These made it necessary to examine performance with a high degree of accuracy.

This paper takes dynamic performance as a comprehensive term for the handling performance, ride comfort, steering feel, brake feel, dynamic performance, and noise and vibration performance that drivers sense subjectively as their impressions of the vehicle. The technology applied to realize the target objectives will be introduced below.

2. Development Concept and Aims

The development concept was a “Red Carpet to a New Era.”[(1)] The meaning packed into this expression refers to the novel appeal, unique to the FCV, in addition to the full

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complement of passenger car performance, ease of use, and other such universal values. In this way, the vehicle is intended to be a special vehicle that will propel the customer into a new era (Fig. 1).

The Accord PHEV, which was launched on the market before the CLARITY FUEL CELL as an environmental vehicle in the same class, was used as the benchmark based on this concept. Goals for dynamic performance were set to surpass that benchmark, as follows.

(1) Electric-power appeal: The speed control performance that is unique to the electric vehicle is communicated to the customer as a point of appeal.

(2) Car appeal: The various types of dynamic performance that provide an impression of the vehicle are communicated to the customer as a point of appeal.

Concerning electric-power appeal, control of acceleration and deceleration are well-known characteristics of electric vehicles, and excellence in this matter is a point of appeal. Therefore, importance was placed on achieving a balance between powerful acceleration, in which there is no delay from the instant the accelerator is pressed down in a stationary car until maximum torque is generated, and sustained smooth acceleration without changing gears after a certain point. Noise originating in the power train was also drastically reduced.

Alternative fuel cars, hybrid cars, and other such cars in categories considered to have a high level of environmental performance are equipped with power train systems that add weight, and with low-RRC tires. Therefore, they require more advanced technology to secure performance that compares with ICE vehicles of the same class in areas such as handling performance, ride comfort, steering feel, brake feel, and noise and vibration. This vehicle was developed so that the kind of dynamic performance that is felt by the driver and passengers as their impression of the vehicle would be equal to or greater than the performance of an ICE vehicle.

Fig. 1 Honda CLARITY FUEL CELL

3. Realizing Electric-power Appeal

3.1. Smooth and Direct Acceleration Sensation

In most ICE vehicles, it is not possible in principle to avoid a time lag from the time the accelerator is pressed until the combustion of fuel is converted into kinetic energy, or to avoid fluctuations in acceleration immediately after acceleration due to the interposition of a torque converter. However, electric vehicles do not experience that kind of loss, nor do they need torque converters. Consequently, they can provide a greater sensation of smooth and direct acceleration than can ICE vehicles. This advantage was used effectively to enliven the driving force characteristics. The default setting that is in effect when the power train is started up is called normal mode. It is configured with the aim of realizing high-quality driving, so that it assures full responsiveness while allowing for smooth driving without any jerking, even when accelerator operation involves some roughness. A sport mode was also configured with greater responsiveness of driving force than normal mode, to allow the experience of driving with a greater range of variation[1].

Figure 2 shows the acceleration in each mode when the accelerator pedal (AP) is pressed to go rapidly from fully closed to 50% open. In an ICE vehicle, the torque amplification effect of the torque converter is lost immediately following acceleration, and a drop in acceleration can be observed when the coupling area is reached. With the CLARITY FUEL CELL, however, acceleration is activated with good response even in normal mode, following which acceleration is maintained without any drop in speed. In sport mode, a balance is achieved between even greater responsiveness and sustained acceleration.

3.2. Operability Capable of Freely Accelerating and Decelerating with the AP

In an electric vehicle, the kinetic energy of the vehicle can be recovered when the AP is off, which means that deceleration characteristics can be configured over a broad range. Therefore, the system was configured to provide acceleration performance with regard to the AP opening of the kind shown in Fig. 3, so that jerking does not occur even with AP operation that is somewhat rough in normal mode, such as during the acceleration described in section 3.1, and so that sport mode provides acceleration and deceleration control that can be felt over a range of

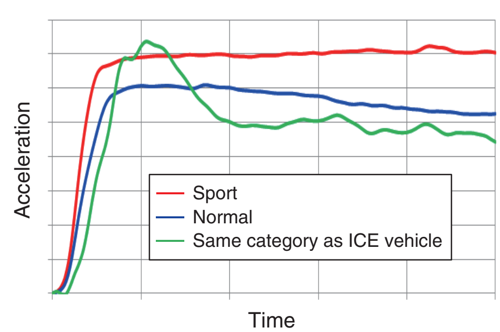

Fig. 2 Acceleration in normal and sport modes with AP (50%)

operation. Figure 4 shows deceleration with respect to vehicle velocity when the AP is fully closed. Sport mode obtains deceleration that is stronger at vehicle speeds that are higher than in normal mode. When the AP is fully closed and the pedal is again pressed down, the acceleration performance shown in Fig. 3 can be achieved, indicating that the range of possible acceleration and deceleration control has been expanded relative to normal mode.

3.3. High Degree of Power Train Quietness

When the FCV is generating electric power, it is supplied with oxygen in the form of air to cause a chemical reaction with hydrogen. Therefore, the CLARITY FUEL CELL is equipped with a motorized turbo compressor[2]. The adoption of this compressor has reduced operating noise by approximately 40% over the previous Lysholm compressors, enhancing cabin quietness from starting up the power train to stopping it (Fig. 5).

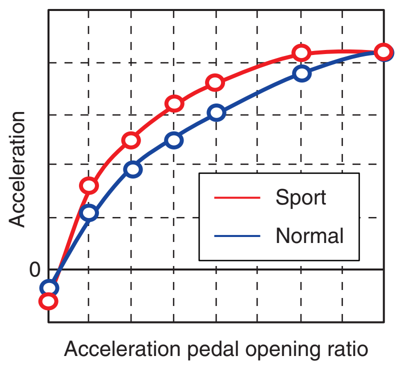

Fig. 3 Acceleration characteristics

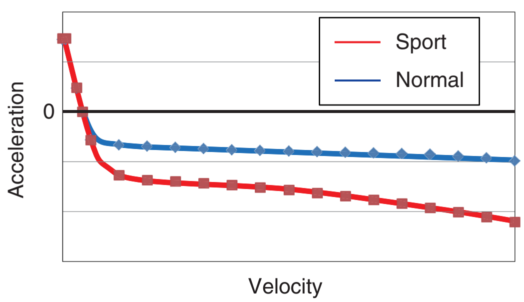

Fig. 4 Deceleration characteristics

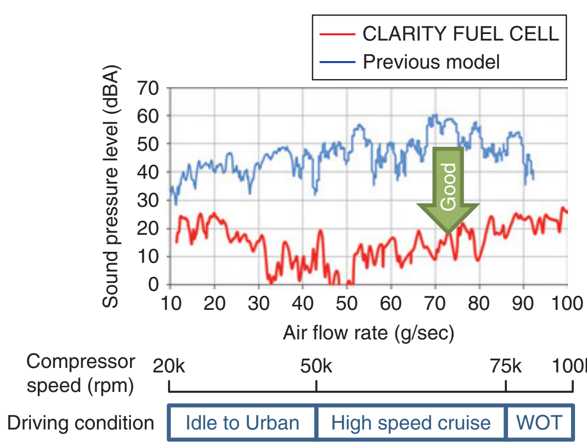

Fig. 5 Reduction of compressor noise in cabin

4. Realizing Car Appeal

4.1. Ease of Line Tracing when Driving

Compared to ordinary ICE vehicles with FF, this vehicle faces two issues: the longitudinal distribution of weight, which tends to be rear-heavy, and the adoption of low-RRC tires. In order to deal with these issues, an investigation of handling performance was carried out through simulations during the initial stage of development. The vehicle specifications, including the height of the center of gravity and the tire size, were incorporated into the initial layout so as to achieve the dynamic performance defined in terms of suspension geometry and other such objectives. The rigidity required in each part of the vehicle body for that purpose was also assured by adopting a unique construction.

Several tire sizes were investigated, from the largest mountable size to the smallest allowable size according to the load factor with respect to wheel load. The characteristics of the tires alone were estimated using statistical tire models, and given the cornering power (CP) characteristics relative to axle load, the choice was narrowed down to two types, 235/45R18 and 225/50R17[3]-[4] (Fig. 6).

Simulations were conducted of the dynamic performance of various types, typified by frequency response, USOS, and double lane changes with the CP characteristics of the various tires, and a comparison was

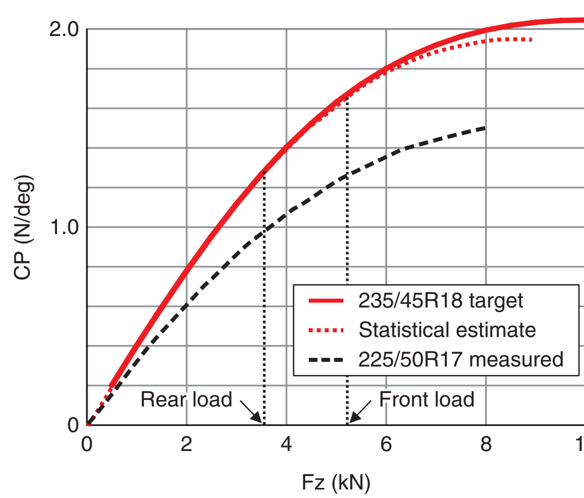

Fig. 6 Measured tire CP (Fz) characteristics of 225/50R17 and target CP (Fz) of 235/45R18

made with the benchmark Accord PHEV. Figure 7 shows the frequency response calculation results as representative of the investigated content.

With the 225/50R17, even when there was a high response gain in a low-frequency band near a steady state condition, it dropped at 1 Hz or higher. With the 235/45R18, however, it was found that response could be enhanced across the entire range. Given these results, the 235/45R18 size tire was selected.

It is well known that in addition to tire grip performance, the rigidity of the rear body and suspension attachment points are important in assuring line tracing performance. However, in order to provide space in the trunk and lower the center of gravity, the hydrogen tank was structured to be cradled in the rear subframe was devised, as shown in Fig. 8. Since this limited the design space, assuring rigidity became an issue. Therefore the rear bulkhead structure shown in Fig. 9 and the structure shown in Fig. 10 that places stiffeners under the rear subframe were devised. In this way, a rear body and suspension attachment structure that is lightweight and highly rigid were successfully realized, so that ease of line tracing is achieved even with the use of low-RRC tires.

4.2. Smooth Ride Feeling

The objective set for ride comfort was to realize a smoothness that is appropriate for the seamless and smooth acceleration performance that is unique to electric vehicles. Therefore, sensitive frequency response dampers (SFRD)[(5)] were adopted. These were also adopted in the

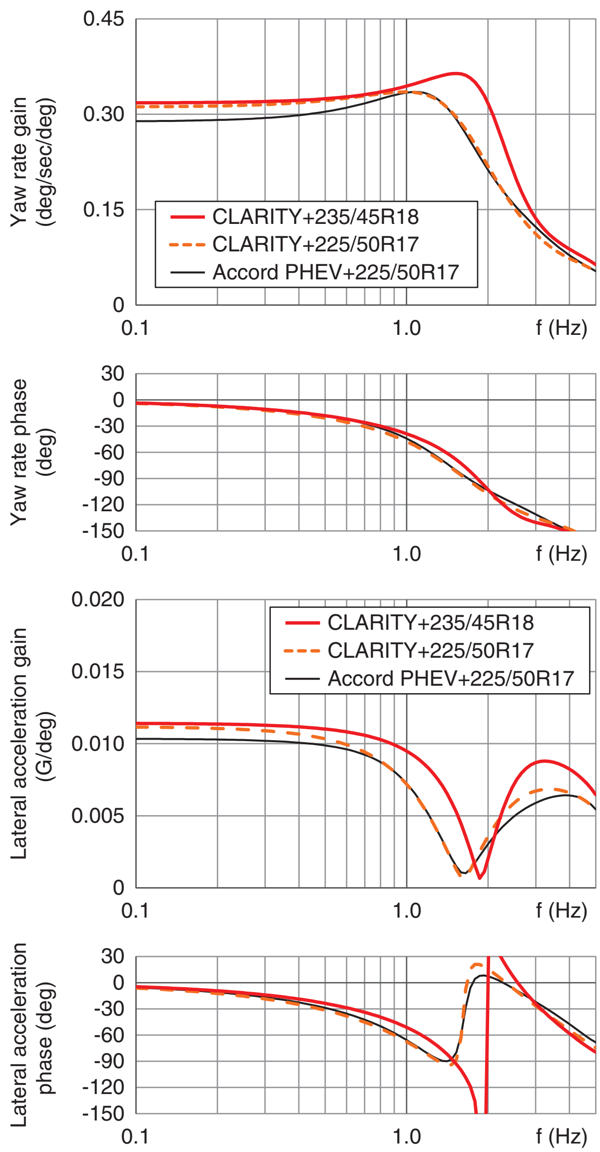

Fig. 7 Bode diagrams of estimated frequency response of yaw rate (upper) and lateral acceleration (lower) with various tire characteristics

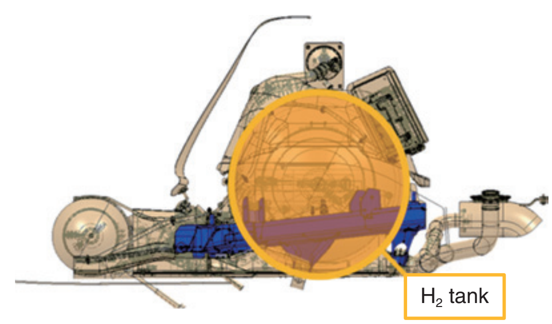

Fig. 8 Side view of rear subframe with H_2 tank

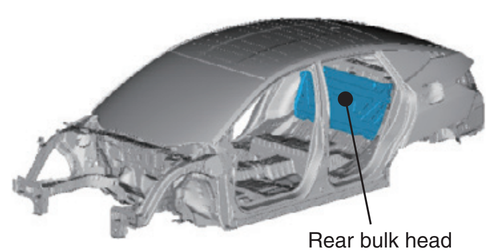

Fig. 9 Rear bulk head

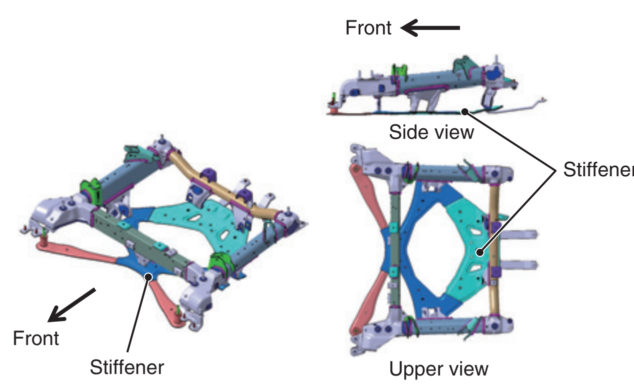

Fig. 10 Rear subframe with stiffener

Accord PHEV, which was launched on the market before this vehicle, and the characteristics of these devices were matched to those of the body described in section 4.1. Running tests were conducted repeatedly under various conditions, and sensory evaluations performed by experts in running tests were used to configure comprehensive settings that included springs, stabilizers, and rubber bushings. The system was raised to a higher level of maturity and the aimed-for dynamic performance was achieved.

4.3. Natural Motion when Changing Course

Vehicles with a low level of handling performance do not readily maintain stable behavior, so they cannot readily be driven smoothly, and passengers also experience discomfort from the motion of the vehicle while it is being driven. Attention was therefore focused on the relationship between the yaw rate and roll with respect to steering wheel operation. By reducing hysteresis and heightening linearity, the predictability of vehicle behavior relative to steering was increased.

Suspension specification values and steering control settings were developed with reference not only to sensory evaluation, but also to actual vehicle behavior based on this conceptual approach. The result was that the vehicle motion when steering was felt to be as natural as or more natural than that of the Accord PHEV that was chosen as the benchmark (Fig. 11).

4.4. Easily Controllable Brakes

For the brakes, the same electric servo brake system[6] used in the Accord PHEV was adopted in order to provide the required performance in a variety of driving scenarios. The objective was defined as realization of an easily controlled brake feel. The method for achieving this was to set the reaction force to the brake pedal stroke. When the degree of deceleration is small, the slope of the pedal reaction force with respect to the stroke is increased in order to increase the reaction force with respect to the stroke. It is set so that the reaction force would increase gradually from that point if the brake pedal is pressed down even further from that point, depending on how far it is pressed. As a result of these measures, the pedal reaction force was made smoothly continuous from the normal operating range to the range where deceleration increases, and brake performance that can be controlled as easily as or more easily than in the benchmark Accord PHEV was realized.

4.5. Quietness with Regard to Road Noise and Wind Noise

The FCV power train is quieter than that of an ICE vehicle. It was reasoned that FCV occupants would therefore be bothered by the intrusion of road noise and wind noise into the cabin as much as or more than the occupants of ICE vehicles, and the target performance for interior quietness was set at a higher level than for an ICE vehicle of the Accord class. As shown in Fig. 13, the absorption of sound in areas close to the noise input source and the insulation of sound along the path of its intrusion were accomplished efficiently. Sound insulating glass was

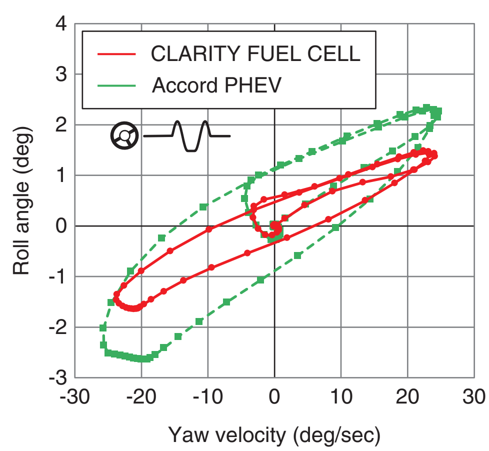

Fig. 11 Relationship between roll and yaw velocity during sinusoidal steer

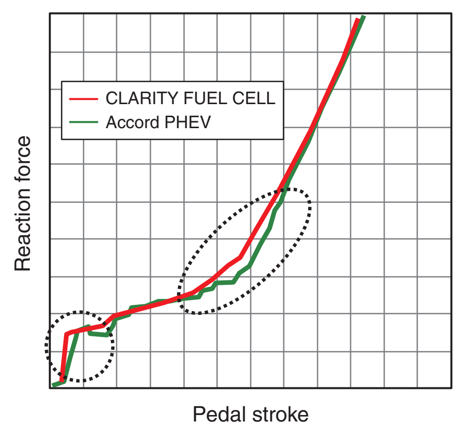

Fig. 12 Relationship between brake pedal stroke and reaction force

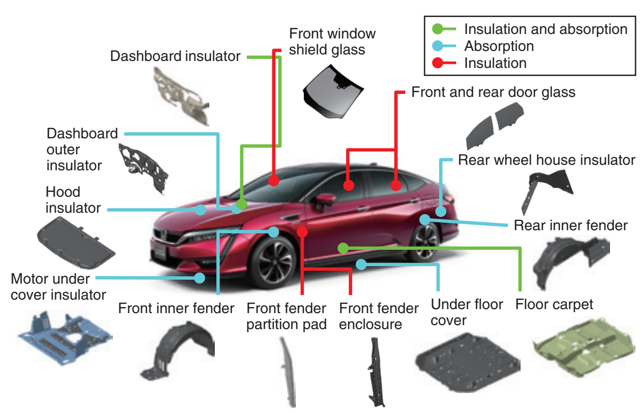

Fig. 13 Sound proof item

also used at many points to reduce noise intrusion.

The floor carpet was made using a multilayered structure that is highly effective in sound insulation and sound absorption. Attachment parts were also produced to reduce the areas of gaps in order to enhance the sound insulation and sound absorption efficiency (Fig. 14).

The wheels were also equipped with resonators in order to limit road noise from tire cavity resonance and shock absorber noise when driving over different levels[(7), (8)] (Fig. 15).

The effects of these measures and the adoption of an active noise control (ANC) system[(9)] achieved road noise performance in the E-segment class, as shown in Fig. 16. Favorable performance was also achieved in wind noise, as shown in Fig. 17.

Fig. 14 Floor carpet layout

Fig. 15 Wheel resonator

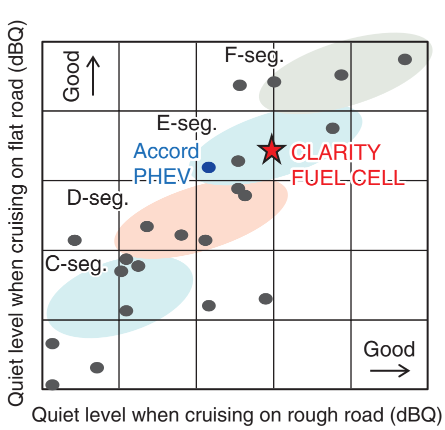

Fig. 16 Quiet feel index (cruising)

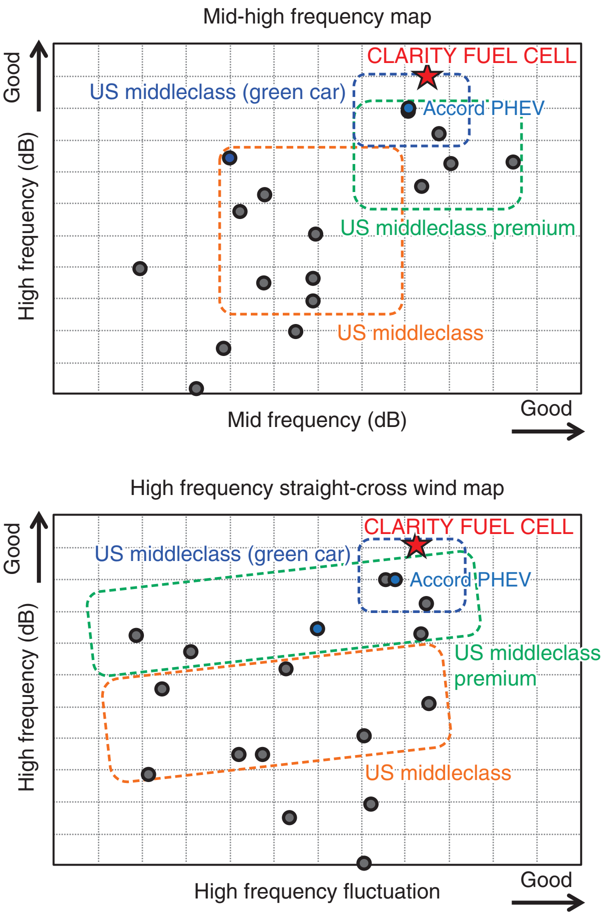

Fig. 17 Wind noise index

5. Conclusion

Development was conducted with the aim of increasing dynamic performance for both electric-power and car appeal. The Accord PHEV was used as the benchmark for the objectives for each, and ways for advancing performance from that level were considered thoroughly from the customer's perspective.

The various aims were achieved using a variety of technologies. As a result of achieving those individual aims, development is considered to have successfully produced a vehicle endowed both with the unique new appeal of an electric vehicle and with the appeal of a car. The hope is that this will become a special car that moves forward with the customer into a new era.

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